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Spiders and harvestmen (Arachnida: Aranei, Opiliones) of the revegetating ash dumps of a combined heat and power plant in Novosibirsk (Russia, West Siberia)

Пауки и сенокосцы (Arachnida: Aranei, Opiliones) зарастающих золоотвалов ТЭЦ Новосибирска (Россия, Западная Сибирь)

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KEY WORDS: Araneae, ash dump, revegetation, soil moisture, taxocen structure.
КЛЮЧЕВЫЕ СЛОВА: Araneae, золоотвал, рекультивация, влажность почвы, структура таксоцена.

ABSTRACT. Spider and harvestman taxocens formed on ash dumps of the combined heat and power plant No. 5 in Novosibirsk (55°00′N, 83°06′E), at different moisture zones of (non)reclaimed sections, as well as in the birch forest adjoining the ash dump (control), have been studied. A total of 70 spider and five harvestman species occurring in the ash dump are recorded. Of the recorded spiders, Lycosidae, Gnaphosidae and Linyphiidae predominated in the ash dump, particularly the actively moving wolf-spiders that are typical of open grasslands. The dominance structure of ground dwelling spiders is similar between all the studied plots both in summer and autumn, and is typical of natural spider communities. Reclamation accelerates the formation of diverse and complex plant communities which positively impact the spider diversity, but show no or little effect on the dynamic spider density. Soil moisture strongly affected the proportion of gnaphosid spiders in the reclaimed section only. A significant effect of the composition and structure of vegetation on the dynamic population density of both spiders and harvestmen within both sections was recorded in autumn. Harvestmen inhabiting the ash dump are typical of antropogenic landscapes; their species diversity was richer in the non-reclaimed section, while a slightly noticeable increase in the population density was observed in the reclaimed section. In sum, by the 9th year of self-restoration of the ash dump, a diverse spider and harvestman community mainly consisting of grassland species typical of open, warm sunny habitats have been formed, with the dominance structure of the spider taxocens being similar to that of undisturbed communities.

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РЕЗЮМЕ. Исследованы таксоцены пауков и сенокосцев, сформировавшиеся на золоотвалах ТЭЦ-5 г. Новосибирска (55°00′N, 83°06′E) в разных по увлажнению зонах нерекультивированной и рекультивированной секций золоотвала, а также в березовом лесу, прилегающем к золоотвалу (контроль). На территории золоотвала отмечено 70 видов пауков и 5 — сенокосцев. Среди пауков на золоотвале доминировали Lycosidae, Gnaphosidae и Linyphiidae с преобладанием бродячих пауков-волков, что характерно для открытых лугово-степных местообитаний. Структура доминирования наземных пауков сходна между всеми исследованными участками как летом, так и осенью, и типична для естественных сообществ пауков. Рекультивация ускоряет формирование разнообразных и сложных по структуре растительных сообществ, что положительно влияет на видовое богатство пауков, при этом не оказывает существенного воздействия на их динамическую плотность. Влажность почвы значительно влияет на долю пауков гнафозид только в рекультивированной секции золоотвала. Существенное влияние состава и структуры растительности на динамическую плотность населения как пауков, так и сенокосцев в обеих секциях золоотвала отмечено осенью. Сенокосцы, населяющие золоотвал, типичны для антропогенных ландшафтов; их видовое богатство было выше в нерекультивированной секции, в то время как незначительное увеличение плотности населения наблюдалось в рекультивированной секции золотвала. В целом, к девятому году самозарастания на золоотвалах формируется разнообразное сообщество пауков и сенокосцев, главным образом состоящее из лугово-степных видов, типичных для открытых и хорошо прогреваемых

местообитаний, при этом структура доминирования таксоценов пауков сходна с таковой в ненарушенных сообществах.

Introduction

With the increasing scale of human influence on nature, the problem of transformation of natural landscapes and ecosystems resulted from a variety of anthropogenic impacts becoming more and more acute. Residents of large cities and industrial centers are most affected by the destruction of natural complexes and the environmental pollution by waste from enterprises and life support facilities of megalopolises. Against this background, there is an increasing demand for studies on ecosystem restoration processes that follow the cessation or mitigation of various negative factors. Such processes as exemplified by various technogenic objects and ecosystems are actively studied in many countries, including Europe (e.g. Vogel, Dunger, 1991; Brussaard *et al*., 1996; Koehler, 2000; Malmström *et al*., 2009; Hacala *et al*., 2020). Yet, in Siberia such studies are still isolated [Lyubechanskii, 2012; Mordkovich *et al*., 2014; Trilikauskas, Luzyanin, 2018; Vorobeychik *et al*., 2019]. Despite a good number of papers being devoted to restoration of various technogenic landscapes, a proportion of the studies devoted to ash dumps of combined heat and power plants (CHPP) is still extremely small both in Europe [Bielska, 1995; Dmowska, 2005; Polchaninova, Foroshchuk, 2013; Schwerk, 2014] and in West Siberia [Novgorodova, 2018; Sheremet *et al*., 2018, 2019; Naumova *et al*., 2019].

Among invertebrates, the ground beetles — the most numerous and diverse groups of ground arthropods — are most commonly used in ecological studies [Skłodowski, 2017; Saint-Germain *et al*., 2005]. Peculiarities of the arachnid communities that are formed at reclaimed ash dumps still remain virtually unexplored. To date, we have found only one study devoted to this problem, undertaken in Ukraine [Polchaninova, Foroshchuk, 2013].

Yet, the study of the restoration processes in ash dump ecosystems as exemplified by arachnids seems to be quite relevant and of a great prospect. Due to a high proportion in soil/ground arthropod communities, short life cycles, ecological and taxonomic diversity, and high mobility, arachnids represent a quite convenient and promising object for studying biota reactions to ecosystem changes. These arthropods quickly respond to any change in their habitat by alterations in spatial distribution of particular groups and a taxocen structure [Hatley, MacMahon, 1980; Robinson, 1981; Łuchak, 1984; Magura *et al*., 2010].

The aim of the present work is to study the taxocens of two arachnid orders formed on overgrown ash dumps under the conditions of absence/presence of reclamation and different degrees of soil moisture.

Material and methods

The investigation was carried out in August–September 2017 and June 2018. The ash dump of the combined heat and power plant No.5 (CHPP) in Novosibirsk (55°00′N, 83°06′E) was chosen as a model in order to study two sections separated by a dam: S1 — a non-reclaimed section of about 17.7 ha, and S2 — a reclaimed one of about 23.7 ha (Fig. 1). The S1 was represented by ash material. In the S2, in the winter of 2010, the surface of the ash and slag was capped by a layer of potentially fertile soils (PFS), which was obtained from a nearby site (0.8–1.4 km off the old ash dump) resulted from the development of a new ash dump for the CHPP No.5. By the beginning of the present research (viz., the 8–9th year of recovery), an active overgrowth process had been observed in both sections. Within each of the two studied sections three similar sized zones corresponding to the estuarine, main and nuclear zones of sedimentation which are characterized by different plant associations were clearly defined (Fig. 1). Taking into account the significant difference in a degree of soil moisture, they were correspondingly named as dry, mesic and wet. A detailed description of the plant communities formed in different zones of each of the two ash dump sections is given by N. Sheremet with the co-authors [Sheremet *et al*., 2018, 2019]. Based on these papers, a brief description of the phytocenoses presented in the study site is given below.

Zones of the non-reclaimed section (S1)

1. DRY. The open herbaceous and smallreed assemblage accompanied by *Hippophaë rhamnoides* L.,

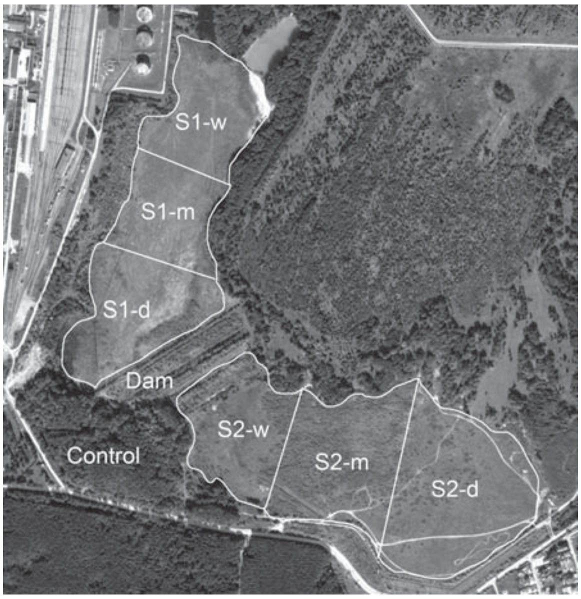


Fig. 1. The location of zones with different soil moisture (d — dry, m — mesic, w — wet) within non-reclaimed (S1) and reclaimed (S2) sections of the ash dump of the Novosibirsk combined heat and power plant (CHPP) No.5 and the control plot of adjacent birch forest.

Рис. 1. Расположение зон с разной степенью увлажнения грунта (d — dry, m — mesic, w — wet) на территории нерекультивированной (S1) и рекультивированной (S2) секций золоотвала ТЭЦ-5 г. Новосибирска и контрольного участка в прилегающем березовом лесу.

with the total projective cover (TPC) — 5%, and the average grass height of 40 cm. Among single herbaceous plants, *Calamagrostis epigeios* (L.) Roth., *Artemisia integrifolia* L., *A. vulgaris* L., *Turritis glabra* L. prevailed. A somewhat mosaic character of the vegetation was due to small groups of *Hippophaë rhamnoides* L. mixed up with *Populus nigra* var. *italica* Münchh. In addition, about 70–80% of the plot was covered with mosses, including *Leptobryum pyriforme* (Hedw.) Wits., and *Bryum sp.*

2. MESIC. Melilot-woodreed phytocenosis, with TPC — 90–100%, and the average grass height of 90 cm. The edificators were *Calamagrostis epigeios* and *Melilotus albus*. A somewhat mosaic vegetation was due to the uneven distribution of *M. albus*. Single plants of *Hippophaë rhamnoides* were recorded.

3. WET. The smallweed-bentgrass phytocenosis, with TPC — 40–50%, the average grass height of 110 cm. Flooded area: hydrophytes *Typha laxmannii* Lepech. and *Phragmites australis* (Cav.) Trin. ex Steud. were noted. Cereals predominated. The edificator was *Calamagrostis epigeios*. The dominant *Agrostis gigantea* Roth. was characterized by an uneven distribution. Single willows of two species (up to 2 m height) were recorded.

Zones of the reclaimed section (S2)

1. DRY. Motley grass-clover-cereal phytocenosis, with TPC — 70%, the average grass height of 70–80 cm. Species edificators: *Phleum pratense* L., *Dactylis glomerata* L., *Calamagrostis epigeios*, *Trifolium hybridum* L., etc. Dominant species among grasses: *Artemisia absinthium* L., *A. dracunculus* L., *A. vulgaris* and *Achillea millefolium* L. Single trees were represented by four species, including *Hippophaë rhamnoides*.

2. MESIC. Motley grass-bean-cereal phytocenosis with sea buckthorn and willow bushes; TPC — 90–100%, average grass height of 80–90 cm. A tree-shrub layer (up to 1.5–2.5 m high) with the dominance of *Hippophaë rhamnoides, Salix caprea* L. *and S. viminalis* L. was formed. Grass dominant species were *Sonchus arvensis* L., *Trifolium* spp. (*T. hybridum* L., *T. pretense* L., *T. repens* L.), *Lactuca serriola* L., *Cirsium setosum* (Willd.) Bess., *Linaria vulgaris* Miller.

3. WET. Clover-bentgrass phytocenosis, with TPC — 60%, the average grass height of 55–60 cm. Flooded area: hydrophyte *Typha latifoli* was recorded. Grass dominant species were: *Calamagrostis epigeios*, *Agrostis gigantea*, *Trifolium pratense*, *T. repens*, *Odontites vulgaris* Moench. Rare trees of *Betula pendula* Roth, *Populus italica* (Du Roi) Moench, *Pinus sylvestris* L., *Salix caprea*, *S. viminalis* and *Hippophaë rhamnoides* were recorded.

Control

A plot of the birch forest adjacent to the ash dump was used as a control. *Aegopodium podagraria* L. and grasses (mainly *Dactylis glomerata* L. and *Festuca pratensis* Huds) predominated in the surface cover. The underwood consisted of *Sorbus sibirica* Hedl., *Viburnum opulus* L., *Crataegus sanguinea* Pall. and *Pinus sylvestris* L. Grey forest soil with moderate moistening was typical of this biotope. Tree crown density was about 60%, TPC — 90%. Such control plot was chosen because a similar biotope was hitherto dominant on the territory allocated for the construction of the CHPP No.5.

In all the zones of the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump, as well as in the control, study plots of about a hectare were selected. The material was collected by pitfall traps. Antifreeze (ethylene glycol) diluted with water in a ratio of 1:5 was used as a preservative. At each of the seven studied plots, three lines of five pitfall traps spaced out at equal intervals (about 2 m apart) were installed at a distance of about 30–70 m from each other (in total, 15 traps per plot). In data analysis, each line of 5 pitfall traps was considered a replicate (in total, three per plot).

A total of 1626 spider and 1829 harvestman specimens were collected and processed, with 6473 trap per days being worked.

Data analysis

Due to the harvestman activity only in the late summer and autumn, the results accounting for them were considered in August–September only. The results of spider quantification conducted at the end of the season (August 10 – September 30, 2017) and in the early summer (June 7–21, 2018) were treated separately as 'autumn' and 'summer', respectively. The data obtained in August and September 2017 were pooled because regional specifics of a phenological autumn in the study site tend to begin from the second half of August.

The initial data on the number of spiders and harvestmen in separate traps have been taken logarithm preliminary with the addition of 1 to eliminate the problem of zero values in the sample. To assess the impact of reclamation, as well as moistening within each section of the ash dump on the spatial distribution of spiders and harvestmen, the One-Way Analysis of Variance (ANOVA) and the post hoc Tukey test were used.

A similar approach has been used to estimate a percentage of the three main spider families (Gnaphosidae, Lycosidae and Linyphiidae) in taxocens. This analysis was carried out only for the data obtained in the early summer, when the spider activity was highest.

When calculating a percentage share of spider families in a population structure and a dynamic density of spiders and harvestmen, both adult and juvenile specimens were taken into account. When calculating the diversity and evenness indices, as well as the degree of dominance of species, only reliably identified specimens of every spider species were used, some juvenile specimens were not taken into account.

A degree of the faunistic similarity between taxocens was estimated by using the Shimkevich-Simpson index [Pesenko, 1982]. In addition, the following measures of diversity were calculated in the PAST package and compared by using the diversity permutation test with the Bonferroni correction: Simpson index (1–D), Shannon index, Bazas-Gibson evenness, and Berger-Parker index (as a ratio of the number of individuals of the dominant species to the total number of individuals). The degree of dominance of separate spider species was evaluated on a logarithmic scale proposed by Yu.P. Pesenko [1982]. According to this technique, the scopes for relative abundance (%) for a sample of 100 specimens correspond to the following scale of the degree of dominance: (0–2.5) — rare 1; (2.5–6.3) — few 2; (6.3–15.8) — common 3; (15.8–39.8) — subdominant 4; (39.8–100) — dominant 5. To understand the relationship between the plots with varying degrees of soil moistening in the non-reclaimed and reclaimed sections of the ash dump and control, the non-metric multidimential scaling (nMDS) analysis based on the Brey-Curtis similarity index was used. The results were analyzed using STATISTICA 6.1, PAST and Microsoft Excel software packages.

Results

Spiders

Taxonomic structure

A total of 82 spider species were identified from the studied territory, among them 14 species are first recorded from Novosibirsk Oblast and one found in the south of West Siberia for the first time (Appendix). It is worth noticing that seven of the species newly found in Novosibirsk Oblast (viz., *Agyneta affinis*, *A. fuscipalpa*, *Attulus caricis*, *A. penicillatus*, *Drassyllus praeficus*, *Talavera thorelli* and *Robertus neglectus*) seem to be restricted to the ash dump only. In most plots of the ash dump, except for the wet zone of S1, the spider taxonomic diversity was higher than in the control (Table 1). Overall, the spider diversity in both S1 and S2 was twice as high as in the control at both genus and family levels. As for the ash dump sections, the spider diversity was slightly higher in the reclaimed section mainly due to diversity of such families as Gnaphosidae, Lycosidae, and Linyphiidae, whereas the non-reclaimed section was characterized by a higher variety of Salticidae, as well as by the presence of Theridiidae (Table 1, Appendix).

In the studied territory, the Lycosidae predominated, with the highest percentage (over 66.4%) being registered from S2. The proportion of Linyphiidae varied from 14.6% in S2 to 28.9% in S1, and to 29.0% in the control. Representatives of the family Gnaphosidae averaged no more than 10% in the ash dump sections, and were not found in the control plot. There were no significant differences in the spider abundance of the main spider families Lycosidae and Linyphiidae between S1, S2 and the control, and of the Gnaphosidae between S1 and S2 as well (Fig. 2). It is worth noticing that S1 was characterized by a relatively high abundance of the linyphiid genera *Erigone* and *Oedothorax* (Appendix), demonstrating a relatively low demand for the presence of plant residues layer.

Table 1. The taxonomic structure of spider communities (the number of taxa) in the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump, including zones of varying degrees of soil moisture, and in the control.
Таблица 1. Таксономическая структура сообществ пауков (число таксонов) нерекультивированной (S1) и рекультивированной (S2) секций золоотвала, включая разные по степени увлажнения зоны, и в контроле.

Taxa	S1				S2				Control
	d	m	w	**total**	d	m	w	**total**	
Dictynidae	–	1	1	**1**	1	1	2	**2**	**–**
Hahnidae	–	–	–	–	–	–	–	–	**2**
Gnaphosidae	4	6	4	**9**	8	5	5	**11**	**–**
Linyphiidae	3	9	6	**9**	10	5	5	**15**	**10**
Liocranidae	–	1	–	**1**	1	1	–	**1**	**–**
Lycosidae	7	10	5	**11**	10	8	12	**14**	**3**
Mimetidae	–	–	–	–	–	1	–	**1**	**–**
Philodromidae	–	1	–	**1**	–	1	1	**1**	**–**
Phrurolithidae	1	–	–	**1**	–	1	1	**1**	**–**
Salticidae	3	3	1	**5**	1	1	1	**2**	**1**
Tetragnathidae	–	2	–	**2**	–	1	–	**1**	**–**
Theridiidae	2	1	–	**3**	–	–	–	–	**–**
Thomisidae	1	3	1	**3**	2	1	1	**4**	**2**
Titanoecidae	1	–	–	**1**	1	–	–	**1**	**–**
Number of families	8	10	6	**12**	8	11	8	**12**	**5**
Number of genera	17	25	15	**32**	21	21	18	**33**	**18**
Number of species	22	37	17	**47**	34	28	26	**54**	**19**

Abbreviations of zones: d — dry, m — mesic, w — wet.

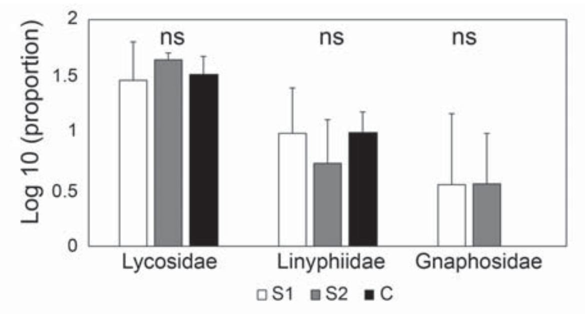


Fig. 2. The percentage of specimens of the three main families in the spider taxocens in different sections of the ash dump and the control in summer. Sections: S1 — non-reclaimed, S2 — reclaimed. ANOVA: ns — no significant differences, p> 0.05. Tukey test: different letters indicate significant differences, p <0.05.

Рис. 2. Доля представителей трех основных семейств в таксоцене пауков в разных секциях золоотвала и контроле летом. Секции: S1 — нерекультивированная, S2 — рекультивированная. ANOVA: ns — значимых различий нет, p>0,05. Критерий Тьюки: разными буквами обозначены значимые различия, p<0,05.

In both S1 and S2, the wolf spiders that are typical of open, mostly meadow-based habitats were diverse and numerous (e.g., *Alopecosa cuneata*, *Pardosa fulvipes*, *P. palustris*, *Trochosa ruricola*). The Shimkevich-Simpson faunistic similarity index between the ash dump sections was 0.660 and appeared to be significantly higher than those obtained by comparing S1 and S2 with the control (0.316 and 0.158, respectively). The Liocranidae and Philodromidae, as well as two *Pachygnatha* species (Tetragnathidae) of which adults do not build webs, were registered in the S1 section only.

Less than a half of the 47 spider species found in S1 were recorded from the dry and wet zones (Table 1); the most diverse were the spiders of the mesic zone. There were no significant differences in percentage shares of the main families of ground-dwelling spiders (Gnaphosidae, Lycosidae, and Linyphiidae) between the spider taxocens of different zones of S1 (Fig. 3); of them, the most numerous were the wolf spiders and the least numerous the gnaphosids. The lowest percentage of Gnaphosidae was observed in the mesic zone, while their share in the dry and wet zones was slightly higher and, on average, had close values.

In S2, the largest species number was registered in the dry zone. However, at a family level, spiders in the mesic zone were more diverse. The wet zone of S2 turned out to be the poorest at all taxonomic levels (Table 1). In the reclaimed ash dump section, as in S1, the most abundant were Lycosidae, accounting for 51.7%. The percentage of Gnaphosidae was found to be decreasing towards the wet zone: significant differences between dry and wet zones were revealed (Fig. 3). The share of Linyphiidae in S2 turned out to be lower than in S1. In the dry and mesic zones of S2, their percentage averaged only 8.5 and 8.2%, respectively, and in both cases was lower than that of the gnaphosids (14.2 and 8.9%, respectively).

In the territory of the non-reclaimed section the highest similarity in species composition was revealed between taxocens of mesic and wet zones: the Shimkevich-Simpson index was 0.941. Unlike S1, in the reclaimed section, the taxocens of these zones were much less similar (0.500), while the highest similarity was found between dry and mesic zones (0.643).

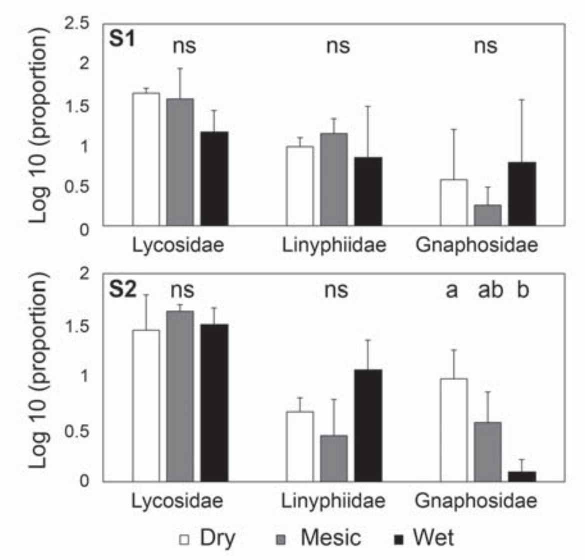


Fig. 3. The percentage of specimens of the three main families in the spider taxocens in zones of the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump with different degrees of moisture in summer. ANOVA: ns — no significant differences, p> 0.05. Tukey test: different letters indicate significant differences, p <0.05.

Рис. 3. Доля представителей трех основных семейств в таксоцене пауков в разных по степени увлажнения зонах нерекультивированной (S1) и рекультивированной (S2) секций золоотвала летом. ANOVA: ns — значимых различий нет, p>0,05. Критерий Тьюки: разными буквами обозначены значимые различия, p<0,05.

Dynamic population density

Some differences in the spider dynamic density in the ash dump and the control were revealed only in

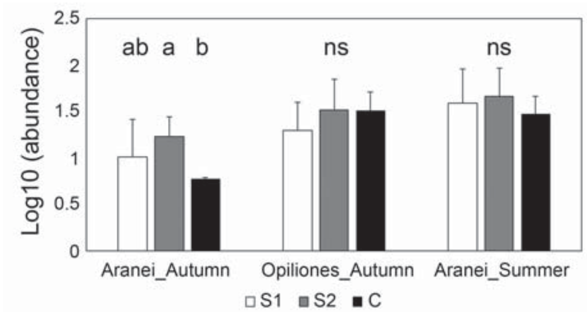


Fig. 4. Dynamic density of spiders and harvestmen in different sections of the ash dump and the control (C). Sections: S1 — non-reclaimed, S2 — reclaimed. ANOVA: ns — no significant differences, p> 0.05. Tukey test: different letters indicate significant differences, p <0.05.

Рис. 4. Динамическая плотность пауков и сенокосцев в разных секциях золоотвала и контроле (С). Секции: S1 — нерекультивированная, S2 — рекультивированная. ANOVA: ns — значимых различий нет, p>0,05. Критерий Тьюки: разными буквами обозначены значимые различия, p<0,05.

autumn (August–September): viz., the density was significantly lower in the control than in S2 (Fig. 4). At the beginning of the season, the dynamic density was relatively higher than in autumn, but differences between sections of the ash dump and the control were non-significant.

The spatial distribution of spiders within both sections of the ash dump turned out to be rather uneven mainly in autumn (Fig. 5). In S1, in autumn, the spider dynamic density was significantly higher in the mesic and wet zones than in the dry one (Fig. 5). At the beginning of the season, the highest dynamic density (97 specimens per 100 trap-days) was registered in the mesic zone. The value of spider density in the wet zone was slightly lower than in other zones, but no significant differences were found. In S2, some differences in the dynamic density between different zones were revealed only at the end of the season: viz., in the dry zone, the values were significantly higher, while the mesic and wet zones practically did not differ from each other (Fig. 5).

Dominance structure

The data on the species composition and the abundance score in spider taxocens of the studied plots are presented in Appendix.

S1-DRY. In summer, 21 spider species were collected in the dry zone of S1, 10 of which were rare. The subdominant *Pardosa agrestis* was the most abundant. The common species included *Attulus distinguendus*,

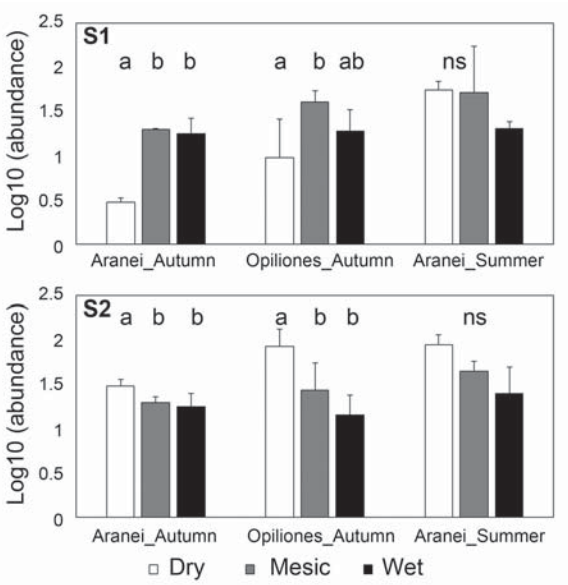


Fig. 5. The dynamic density of spiders and harvestmen in zones with varying degrees of soil moisture in the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump. ANOVA: ns — no significant differences, p> 0.05. Tukey test: different letters indicate significant differences, p <0.05.

Рис. 5. Динамическая плотность пауков и сенокосцев в разных по степени увлажнения зонах нерекультивированной (S1) и рекультивированной (S2) секций золоотвала. ANOVA: ns — значимых различий нет, p>0,05. Критерий Тьюки: разными буквами обозначены значимые различия, p<0,05.

Erigone atra, *Micaria silesiaca*, *Steatoda albomaculata*, *Trochosa ruricola* and *Xerolycosa miniata*. The remaining species were few, regarding their relative abundance. In autumn, six species were registered (Appendix). The subdominant *Phrurolithus festivus* was the most abundant. *Attulus distinguendus* that was common at the beginning of summer became few by the scale of abundance score. The remaining species were rare in this period.

S1-MESIC. In summer, 25 species were registered in the mesic zone of S1. *Pardosa agrestis* was the dominant. The common species were *Erigone atra*, *E. dentipalpis*, *Pardosa fulvipes*, *P. palustris* and *Xerolycosa miniata*. There were 14 rare spider species. The remaining species were few. In autumn, the species number of the S1-mesic zone decreased to 17. The subdominant *Alopecosa cuneata* became the most abundant. *Centromerus sylvaticus* and *Trochosa ruricola* were common in this period, and 10 spider species were rare. The remaining species were few.

S1-WET. In summer, 12 species were found in the wet zone of S1. The subdominant *Erigone dentipalpis* was the most abundant in this period. Only *Erigone atra* turned out to be common. Rare spiders included eight species. The remaining species were few. In autumn, 11 species were registered. There were two subdominant species: viz., *Erigone dentipalpis* and *Trochosa ruricola*. Spiders of three species were rare. The remaining species were few.

S2-DRY. In summer, spiders of 26 species were captured in the dry zone of S2. The subdominants were *Alopecosa cuneata*, *Pardosa agrestis* and *P. palustris*. The common spiders included *Argenna subnigra*, *Micaria silesiaca*, *Pardosa fulvipes*, *Trochosa ruricola* and *Xerolycosa miniata*. Spiders of 14 species were rare. The remaining species were few. In autumn, 16 species were noted. Subdominants included *Alopecosa cuneata*, *Spiracme striatipes* and *Trochosa ruricola*. Only *Zelotes longipes* turned out to be common. Spiders of nine species were rare. The remaining species were few.

S2-MESIC. In summer, 26 species were recorded in the mesic zone of S2. The subdominants were *Pardosa fulvipes*, *P. lugubris* and *Trochosa ruricola*. The common species included *Alopecosa cuneata* and *Pardosa agrestis*. Spiders of 17 species were rare. The remaining species were few. In autumn, the spider taxocen was much poorer and included only eight species. The most abundant were subdominants *Alopecosa cuneata* and *Trochosa ruricola*. Only *Zelotes latreillei* turned out to be common. Spiders of two species were rare. The remaining species were few.

S2-WET. In summer, the spider taxocen of the wet zone of S2 included 19 species, of which 13 were rare. The subdominants were *Erigone atra* and *Pardosa agrestis*. *Argenna patula* and *Trochosa ruricola* were common. The remaining species were few. In autumn, only 13 species were registered, of which eight were rare. *Trochosa ruricola* became a dominant species.

Table 2. Diversity indices of spider taxocenes in the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump within zones with different degrees of soil moisture, and in the control. Different letters in the lines indicate significant differences (diversity permutation test with the Bonferroni correction, p <0.002).
Таблица 2. Показатели разнообразия таксоценов пауков нерекультивированной (S1) и рекультивированной (S2) секций золоотвала в зонах с разной степенью увлажнения грунта и в контроле. Разными буквами в строчках обозначены значимые различия (пермутационный критерий с учетом поправки Бонферрони, p<0,002).

Indices	Season	S1			S2			Control
		d	m	w	d	m	w	
Shannon	Sum	2.58 ^{a}	2.18 ^{ab}	1.87 ^{ab}	2.50 ^{a}	2.50 ^{ab}	2.23 ^{ab}	1.77 ^{b}
	Aut	1.12^{a}	2.13^{b}	1.85^{ab}	1.94^{b}	1.65^{ab}	1.76^{ab}	1.81^{ab}
Simpson index	Sum	0.90 ^{a}	0.78 ^{bc}	0.75 ^{bc}	0.89^{a}	0.87^{a}	0.84^{ab}	0.70^{c}
	Aut	0.51^{a}	0.81^{b}	0.77^{b}	0.80^{b}	0.76^{b}	0.70^{b}	0.77^{b}
Buzas-Gibson Evenness	Sum	0.63 ^{a}	0.35 ^{b}	0.54 ^{ab}	0.49 ^{ab}	0.49 ^{ab}	0.55 ^{ab}	0.42 ^{ab}
	Aut	0.38 ^{a}	0.49 ^{a}	0.49 ^{a}	0.43 ^{a}	0.65 ^{a}	0.45 ^{a}	0.61 ^{a}
Berger-Parker	Sum	0.18 ^{a}	0.43 ^{b}	0.45 ^{bc}	0.22 ^{a}	0.25 ^{ac}	0.32 ^{ab}	0.51 ^{b}
	Aut	0.68 ^{a}	0.38 ^{b}	0.38 ^{bc}	0.34 ^{b}	0.34 ^{b}	0.52 ^{ac}	0.36 ^{ab}

Abbreviations of zones: d — dry, m — mesic, w — wet.

Alopecosa cuneata was common. The remaining species were few.

A comparative analysis of the diversity parameters of spider taxocens of S1 and S2 sections revealed that the summer taxocen of the reclaimed section was more diverse than that of the non-reclaimed section by all indices, but the differences were significant only for the Simpson and Berger-Parker indices (p=0.0001 in both cases). In autumn, differences between all indices were non-significant.

Results of a comparative analysis of the diversity parameters of spider taxocens formed in (non)reclaimed sections of the ash dump within zones of different degrees of soil moisture and in the control are given in Table 2; both summer and autumn data are included.

In S1, in summer, the highest numerical values of evenness by the Shannon and Simpson indices and the lowest value by the Berger-Parker index were typical of the dry zone. There were no significant differences by the Shannon index between different zones of S1, while differences between the dry zone of this section and the control were significant. Significant differences in the values of Simpson index were revealed when comparing the dry with the mesic and wet zones of S1 and the control as well; yet, the differences between the mesic and wet zones of S1 and the control were non-significant. Significant differences in the evenness were found between the dry and mesic zones of the non-reclaimed section only. Significant differences in the values of Berger-Parker index were revealed when comparing the dry zone of S1 with the mesic and wet zones of the same section of the ash dump, and with the control as well.

In autumn, the situation changed. The Shannon and Simpson indices were higher in the mesic zone of S1, while significant differences in both cases were revealed only when comparing the mesic and dry zones of S1. The evenness and the Berger-Parker indices had the same values in the mesic and wet zones of S1 and formally characterize these taxocens as being more diverse as compared to those of the dry zone of the same section. There were no significant differences in the evenness between different zones of S1 and the control as well. As for the Berger-Parker index, significant differences were found when comparing the dry zone with both the mesic and wet zones of S1, and the control as well.

In S2, differences between all the calculated summer indices were non-significant. In summer, significant differences in the Shannon indices were only found when comparing the dry zone of S2 with the control. Significant differences in the values of Simpson index were revealed when comparing the dry, mesic and wet zones of S2 with the control. There were no significant differences in the evenness between different zones of S2 and the control as well. As for the Berger-Parker index, significant differences were found when comparing both the dry and mesic zones of S2 with the control.

In autumn, there were no significant differences when comparing both the Shannon and the Simpson indices and the evenness between different zones of S2 and the control as well. Significant differences in the Berger-Parker indices were only found when comparing the wet zone of S2 with other zones of this section and with the control as well.

An analysis of spider taxocens in different zones of the two sections of the ash dump and in the control by non-metric multidimensional scaling on the Bray-Curtis index are presented in Fig. 6. In summer, taxocens of separate zones of both the non-reclaimed and reclaimed sections were separated from each other in the plane of the two axes. Two pairs of taxocens — those of the dry zone of S1 section and the wet zone of S2 in the first case, and those of the dry zone of S2 section and the mesic zone of S1 section in the second case — were the closest. The control plot of the birch forest was well separated from all zones of the ash dump. In

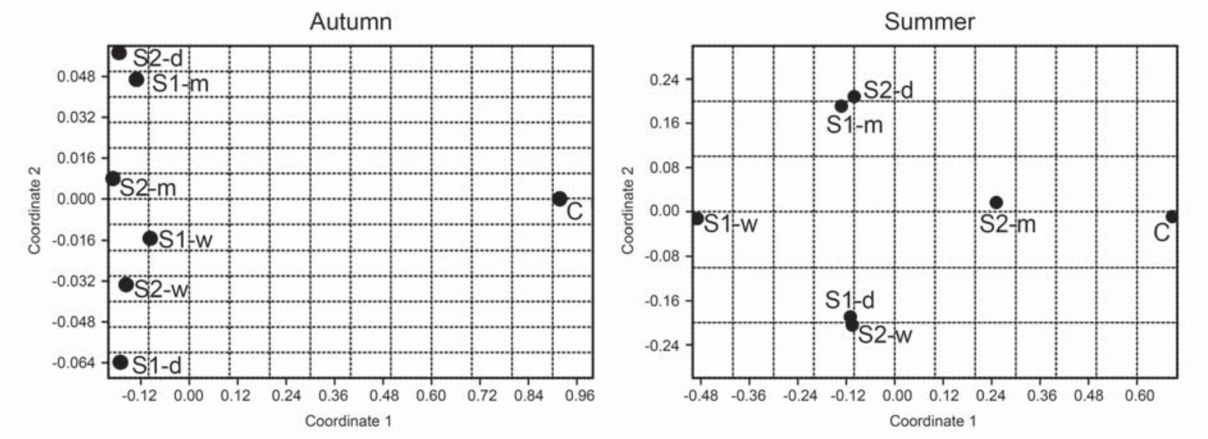


Fig. 6. Non-metric multidimential scaling (nMDS) analysis of the relationship between spider taxocens of zones with varying degrees of soil moisture (d — dry, m — mesic, w — wet) in the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump of CHPP (Novosibirsk) and adjacent birch forest (control) based on the Brey-Curtis similarity index.

Рис. 6. Результаты анализа неметрического многомерного шкалирования (nMDS) таксоценов пауков в различных по увлажненности зонах (d — сухая, m — умеренно влажная, w — влажная) золоотвала ТЭЦ-5 г. Новосибирска и прилежащего березового леса (контроль) по индексу Брея-Кёртиса.

summer, the mesic zone of the reclaimed section is the closest to it.

In autumn, all zones of both sections formed a common cluster oriented along the vertical axis. The control birch forest became more isolated from all zones of the ash dump.

Harvestmen

Taxonomic structure

A total of five harvestman species of the family Phalangiidae were found in the studied territory (Table 3). One of them was not identified to species, since the collected material consisted of juveniles and females only. The record of *Odiellus lendii* is new to Siberia. Earlier, this species was known from the fauna of Europe only [Chemeris, Kovblyuk, 2005; Mayshanova *et al*., 2012]. Harvestmen occurring in the ash dump belong to epigeic forms, with the exception of *Phalangium opilio* which also inhabits grass. In S1, all five species were present, while in S2 and the control plot fewer harvestmen were found: three and two species, respectively (Table 3).

Dynamic population density

Harvestmen were distributed quite evenly across the studied territory: viz., there were no significant differences in their dynamic density between both sections of the ash dump and the control plot (Fig. 4). The lowest dynamic density (on average 25 individuals per 100 trap-days) was registered in the non-reclaimed section, the highest (on average 46 individuals per 100 trap-days) was in the reclaimed section. The spatial distribution of harvestmen within both sections of the ash dump was quite uneven (Fig. 5). At S1 section, the highest dynamic density was observed in the mesic zone (about 40 specimens per 100 trap-days); yet, significant differences were revealed between the mesic

Table 3. The number of specimens of harvestmen collected from the non-reclaimed (S1) and reclaimed (S2) sections of the ash dump, including zones with different degrees of soil moisture, and in the control.

Таблица 3. Число экземпляров разных видов сенокосцев, собранных на территории нерекультивированной (S1) и рекультивированной (S2) секций золоотвала, включая разные по степени увлажнения зоны, и в контроле.

Taxa	S1				S2				Control
	d	m	w	total	d	m	w	total	
Phalangiidae									
Odiellus lendii (Soerensen, 1894)	77	184	33	294	598	197	106	901	198
Oligolophus tridens (C.L. Koch, 1836)	1	5	0	6	24	20	1	45	66
Opilio parietinus (De Geer, 1778)	3	0	0	3	0	0	0	0	0
Phalangium opilio Linnaeus, 1761	21	112	82	215	85	12	10	107	0
Genus sp.	2	4	0	6	0	0	0	0	0

Abbreviations of zones: d — dry, m — mesic, w — wet.

and dry zones only (Fig. 5). At S2 section, a significantly higher dynamic harvestman density (more than 90 specimens per 100 trap-days) was observed in the dry zone, while the values of the mesic and wet zones were quite similar (Fig. 5), accounting for about 15 specimens per 100 trap-days.

Dominance structure

In both sections of the ash dump, the most abundant species were *Odiellus lendii* and *Phalangium opilio* (Table 3). It is worth noticing that the dynamic density of *Oligolophus tridens* and *Odiellus lendii* was three times higher in S2 than in S1, while the density of *Phalangium opilio* was two times lower in S2 than in S1. In the control plot, only two species were found: viz., *Odiellus lendii* and *Oligolophus tridens*. The dynamic density of the latter in the birch forest was 3–9 times higher than in either plot of the ash dump.

In S1, the species richness decreases along the gradient of soil moisture reduction from five species in the dry zone to two species in the wet zone (Table 3). *Opilio parietinus* was found in the dry zone of this section only. The harvestman species composition in S2 of all zones was the same and consisted of three species (Table 3).

Discussion

During the almost 9-year period of self-restoration of the CHPP ash dump combined with the process of colonization by vegetation, the formation of spider and harvestman communities takes place. The application of a layer of potentially fertile soil to one of the sections of the ash dump accelerated the development of vegetation cover, made it more diverse floristically and more complex and heterogeneous in its structure [Sheremet *et al*., 2019]. At the same time, the habitat for ground arthropods became more stable as far as the temperature concerns and more favorable in terms of the shelter availability for spiders, their egg-laying and juveniles, which had affected the spider diversity and abundance.

The dominant position of Lycosidae (wolf spiders) in all areas of the ash dump seems to be quite natural, since at all life stages these spiders actively move in search of prey or sexual partner and do not require a permanent shelter. It is the lycosids of which six species inhabit five/all ash dump zones. These are species typical of open grasslands: viz., *Alopecosa cuneata*, *Pardosa agrestis*, *P. fulvipes*, *P. lugubris*, *Trochosa ruricola* and *Xerolycosa miniata.* Only among representatives of this family there were species included in dominant complexes of 3–4 zones of the studied ash dump sections. Common meadow dwellers *Pardosa agrestis* and *Trochosa ruricola* appeared to be the most abundant.

Unlike the wolf spiders, the equally mobile gnaphosids prefer open, warm and dry habitats and need shelters where females can produce and protect their egg cocoons. Therefore, despite a comparable taxonomic diversity, representatives of this family were less abundant than the lycosids in all plots of the ash dump. The linyphids represent the largest spider family in the temperate zone, being, due to peculiarities of their ecology, a sort of 'wandering variant of web spiders' [Eskov, 1981]. Most species are small-sized and associated with the soil layer, plant debris or forest litter. Only a few species can be numerous in the biotopes lacking the litter. It is precisely those species that turned out to be the most widespread and abundant in the studied CHPP ash dump: viz., *Erigone atra*, *E. dentipalpis* and *Oedothorax apicatus*. Spiders of the genus *Erigone* were among dominant species in the wet zones of ash dump sections. They formed the base of the spider population in the studied territory and, together with the aforementioned species of Lycosidae, are typical of meadow and other open biotopes. Other families also included species that were quite common in the areas of both sections of the ash dump, for example, *Argenna subnigra* (Dictynidae), *Zelotes latreillei* (Gnaphosidae), *Spiracme striatipes* (Thomisidae). But only the latter species was part of the dominant complex and only in the dry zone of the reclaimed section.

It is worth noticing that only a third of the lycosid species were found in 1–2 zones of the ash dump, whereas a proportion of such species among the linyphids and the gnaphosids was about 50%. All recorded species of Dictynidae, Liocranidae, Mimetidae, Tetragnathidae, Theridiidae and Titanoecidae, as well as most of the Salticidae and Thomisidae, were also recorded from two or less zones of the ash dump. As for the Hahnidae, none of its species was found in the ash dump.

Thus, both sections of the ash dump were populated mainly by non-forest spider species, suggesting that the spider population of such technogenic landscapes is not formed by the species from neighbouring forests. This observation is also supported by low indices of the faunistic similarity between the study plots and the control birch forest. The main source of new settlers seems to have been adjacent anthropogenic territories. According to unpublished data of the first author (LT) on the spider urban fauna of Novosibirsk and other cities/towns of Novosibirsk and Kemerovo Areas, anthropogenic territories are characterized by a specific spider fauna that includes euritopic species, as well as those typical of steppe and meadow habitats, but adapted to live in megalopolitan territories. The studied ash dump appeared to be quite similar to such anthropogenic territories. In open, warm sunny plots of the ash dump, with a well-developed grass layer, more diverse spider taxocens were formed, as compared to that of the birch forest. Similar results were obtained in the study of meadow fallows and birch forests of various ages in Mordovia [Agafonova *et al*., 2019].

A layer of potentially fertile soils (PFS) applied as a cover to the ash dump in a short period of time has

resulted in the development of a whole complex of habitats similar to the cereal and motley grass meadows. A well-developed grass layer with high projective cover values was formed in the reclaimed section [Sheremet *et al*., 2019]. A dense network of creeping shoots of clover and cereal rhizomes was formed on the surface and upper layer of the soil, hence providing spiders with plethora of microhabitats. In addition, this helped to preserve moisture in the upper soil layers and prevented its overheating. Although in the non-reclaimed section there were only nine ground-dwelling linyphiid species, in the reclaimed section their number already reached 15 species. The spider abundance was slightly higher in the reclaimed section than in the non-reclaimed area (54 and 47 species, respectively). At the same time, at a genus or family level, the taxonomic richness of both sections was quite similar. The significant differences between S1 and S2 by the Simpson's Diversity and Berger-Parker indices during the period of maximum spider activity in June are evidence for the spider taxocen of the reclaimed section being more diverse.

Both in summer and in autumn, the dominance structure of spider taxocens between non-reclaimed and reclaimed sections, as well as those of all the plots studied, showed no significant differences. Elsewhere, there were few abundant and lots of rare and less abundant species in spider taxocens, which is quite common for Aranei [Esyunin, Shumilovskikh, 2008; Agafonova *et al*., 2019]. Thus, the process of populating ash dumps by spiders proceeds quite quickly, and by the 9th year of self-revegetation had resulted in the formation of spider communities typical of undisturbed landscapes. At the same time, reclamation has a certain impact on the structure of spider taxocens, which is reflected in differences between the values of both Simpson and Berger-Parker diversity indices.

In summer, despite the spider dynamic density being relatively higher in the ash dump as compared to the control plot, there were no significant differences. This is likely to be due to high activity and relatively uniform spatial distribution of wandering spiders dominating the ash dump. Significant differences in the spider spatial distribution between the reclaimed section of the ash dump and birch forest in the autumn period seems to be associated with increased abundance of *Alopecosa cuneata* and *Trochosa ruricola*. The latter species usually displays spring and autumn breeding periods and requires a substantial soil layer. It seems to aggregate in the reclaimed ash dump in autumn, preparing for overwinter. In autumn, *A. cuneata* was represented by juveniles, which were much more abundant in S2 than in S1. This could also be related to the search for places with better developed vegetation and soil which could be suitable for overwintering. In autumn, in the non-reclaimed section both species were few by the scale of abundance score, being absent from the control birch forest. Yet, in autumn, their share in the spider spatial distribution was decisive in S2, which could explain the registered significant difference with the control plot, where in autumn the wolf spiders are as rare as in the S1 section.

Overall, the harvestmen occurring in the CHPP ash dump showed similar trends, except for *Oligolophus tridens* (see above). They were more diverse and abundant in the ash dump sections than in the control plot. In the reclaimed section, their dynamic density was higher than in the non-reclaimed section. In autumn, the harvestman spatial distribution significantly differed between the dry and mesic zones of S2. However, the species composition of the non-reclaimed section turned out to be richer. The four identified species are typical of both natural and anthropogenic landscapes [Tchemeris *et al*., 1998; Mayshanova *et al*., 2012]. Ecologically, due to high mobility and the absence of catching snares, this arachnid group is close to wandering spiders. The species composition revealed at the ash dump is typical of various transformed habitats. Only *Oligolophus tridens* could be considered a forest species, since it is one of the most abundant harvestmen of the southern Siberian forests [Trilikauskas, 2015]. It is likely that this species could have penetrated the ash dump from the adjacent birch forest, which is indirectly reflected in Table 3.

Investigation of the spider taxocens across zones with varying degrees of soil moisture in the non-reclaimed section showed that the diversity at all taxonomic levels is higher in the mesic zone. At the same time, in summer, all the diversity indices turned out to be higher in the dry zone, which differed significantly by three indices from the mesic zone and by two indices from the wet zone. There were no significant differences between the mesic and wet zones of the section S1. In S2, the dry zone appeared to be the richest by its species abundance. Indices based on other taxonomic levels (genera and families) showed no difference between all zones with varying degrees of soil moisture. There were no significant differences between the diversity indices, except for the Berger-Parker dominance index. Its values differed significantly when comparing dry and wet zones in autumn. Among three main spider families (Gnaphosidae, Lycosidae, and Linyphiidae) significant differences between the dry and wet zones were only revealed for the gnaphosids in S2. The latter spider group is typical of dry areas and hence is most sensitive to increasing humidity. The share of Gnaphosidae, the overall summer and autumn spider dynamic density and the harvestman dynamic density in the reclaimed section decreased along the moisture gradient, from the dry to wet zones.

According to the non-metric multidimential scaling (nMDS) analysis based on the Brey-Curtis similarity index, the control plot was strongly separated from the ash dump plots both in summer and in autumn. In summer, different zones within both S1 and S2 are clearly separated on the diagram (Fig. 6), while the closer positions are occupied by the zones of different sections of the ash dump. Thus, a close position of

summer and autumn structure of spider taxocens of the dry S2 and mesic S1 sections of the ash dump is likely to be explained by a certain similarity of their phytocenoses characterized by well-developed, not too wet meadow vegetation with single trees. At the same time, a close position of spider taxocens of the dry S1 and wet S2 sections is rather surprising. Various factors could affect the spider taxocen structure of revegetating territories. One of the possible plausible explanations of the latter result could be the whereabouts of these areas, as well as the presence of the dam separating them (Fig. 1). First, the dam itself could be a source of settlers for both areas (unfortunately, the dam spider taxocen was not investigated). In addition, the dam could not prevent migrations of actively moving spiders during period of their high activity. In both cases, the S1-dry and S2-wet zones could serve as transit zones, which could partially explain their closeness on the graph as well. However, the data obtained at this time are insufficient to explain the observed result and hence the matter requires an additional rigorous investigation.

Conclusion

In the entire studied territory, including both the ash dump and the control forest, 82 spider species and five harvestman species have been recorded, of which 14 spider species are recorded from Novosibirsk Oblast for the first time, one spider species was recorded for the first time in the south of West Siberia, and one harvestman species was recorded new to the fauna of Siberia.

Spiders of 70 species in 13 families are found to occur in the ash dump, of which 63 species are confined to it. In the spider taxocens of the ash dump, Lycosidae, Gnaphosidae and Linyphiidae predominate, whereas Theridiidae and Liocranidae are restricted either to non-reclaimed or to reclaimed sections respectively. Actively moving wolf spiders, which are typical of opened grasslands and likely to have penetrated the ash dump from adjacent urban areas, predominated, with *Pardosa agrestis* and *Trochosa ruricola* being the most abundant. The dominance structure of the ground dwelling spider taxocen formed in both the non-reclaimed and reclaimed sections appear to be typical of natural regional undisturbed spider communities and is quite similar in all explored plots both in summer and in autumn.

Covering ash and slag with a potentially fertile soil cap layer accelerates the formation of plant communities with a complex composition and structure which should enhance the spider diversity. Yet, an effect of the latter factor on the spider dynamic density was not obvious at the studied stage of self-restoration of the ash dump. Nevertheless, significant differences in the spider spatial distribution between the reclaimed section of the ash dump and the control birch forest were registered in autumn; they are likely to be due to the increased abundance of *Alopecosa cuneata and Trochosa ruricola.* Soil moisture had practically no effect on the proportion of lycosids and linyphids in spider taxocens, while the share of gnaphosids in the reclaimed section was strongly affected by this factor. A significant effect of soil moisture on the dynamic population density of both spiders and harvestmen within both sections was observed in autumn.

Harvestman taxocens formed in the CHPP ash dump are also represented mainly by the species typical of transformed landscapes. The species diversity appears to be richer in the non-reclaimed section. Although a slight tendency of increasing the harvestman population density was observed in the reclaimed section, no significant differences between both sections of the ash dump and the control birch forest were revealed.

It is unlikely that some of the spider and harvestman species found in the study site could have been brought with the soil used for capping the ash/slag dump. Otherwise, reclamation would have had a more significant effect on both their diversity and abundance. Yet, since the PFS material used for reclamation was obtained from the close vicinity of the study site (within the distance of 0.8–1.4 km), wandering groups of spiders and harvestmen could have easily moved from that area and inhabit the ash dump.

Overall, the repopulating of the ash dump by spiders and harvestmen proceeds rather quickly. By the 9th year of self-restoration of the ash dump, a diverse community of spiders and harvestmen mainly consisting of grassland species typical of open, warm sunny habitats have been formed, with the dominance structure of spider taxocens similar to that of undisturbed communities.

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